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Integrated Panoramic Night Vision Goggle

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ABSTRACT

In July of 1999 the Air Force Research Laboratory (AFRL) took delivery of the last of twelve panoramic night vision goggle (PNVG) systems. Data on these systems has been collected onboard a variety of aircraft including the F-15C, F-15E, F-16, A-10, F-117, C-17, C-5, C-130, and HH-60 aircraft. Data will continue to be collected on these aircraft as well as other platforms over the next 12 months. In April of 2000 a follow-on development effort was initiated entitled "Integrated Panoramic Night Vision Goggle" (I-PNVG). Lessons learned from the PNVG effort are being incorporated into the I-PNVG program wherever possible. Specific objectives to be addressed under I-PNVG effort are wide field-of-view, integrated laser protection, fit/comfort, image quality, integrated symbology/imagery display, field support, ejection/crash/ground egress safety, compatibility with existing systems, affordability, supportability, maintainability, producibility, and reliability. This paper will briefly discuss pilot comments about the PNVG, provide further detail of the I-PNVG objectives, and address I-PNVG design considerations.

INTRODUCTION

A Small Business Innovative Research (SBIR) phase II program that ended in July 1999 resulted in the delivery of seven PNVG I and five PNVG II prototype systems. The PNVG I version is a low profile design for ejection seat aircraft with the goal of retaining the goggle safely on the head throughout the entire ejection sequence.

Figure 1: PNVG I in F-15E (front cockpit)

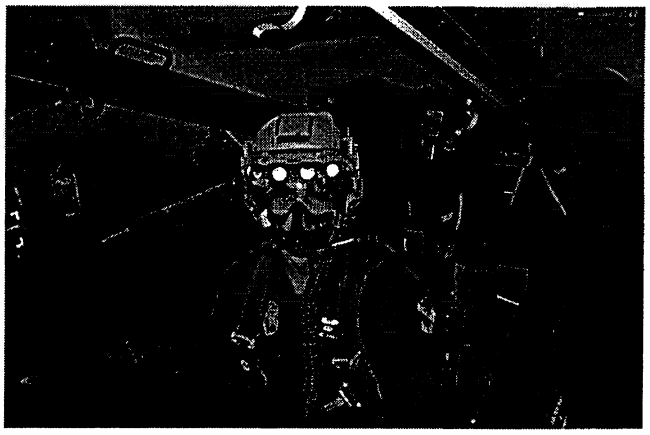

Figure 2: PNVG I in an F-15E (rear cockpit)

The PNVG II approach, which looks more like a traditional goggle, attaches to any existing AN/AVS-6 or F-4949 mounting system. This version was intended for transports, helicopters, and ground personnel. Both PNVG I (Figure 1 and Figure 2) and PNVG II (Figure 3) provide a 100 degree horizontal by 40 degree vertical (100° H X 40° V) intensified field of view (FOV) (Figure 4.). This represents a greater than 160% increase of the warfighter's intensified image compared to currently fielded 40° F-4949 system (Figure 5 and Figure 6.). A follow-on advanced technology development program, I-PNVG, was awarded in April 2000 to optimize the wide FOV concept and address deficiencies of the SBIR PNVG I and SBIR PNVG II systems identified during recent flight tests. Additionally, the I-PNVG will integrate (or have the "hooks" available to integrate) laser eye protection and laser hardening technologies as they become mature enough for insertion. The I-PNVG program was awarded to Insight Technology Incorporated with ITT Night Vision as their primary teaming member. The program is managed by the Helmet-Mounted Sensory Technologies Program Office within the Air Force Research

Laboratory at Wright-Patterson AFB OH. The Army has also joined the team to complement the Air Force's effort to develop this next-generation night vision goggle.

Figure 3: PNVG II in C-17 Cockpit

Figure 4: 100 x 40 Degree Field of View

BACKGROUND

NVGs with FOVs ranging from 30 degrees to 45 degrees have been used in military aviation for more than 20 years. The vast majority of NVGs (AN/AVS-6 and F-4949) provide a 40 degree binocular FOV. Because each ocular uses only a single Image intensifier (I^2) tube, increased FOV for these NVGs can only be obtained at the expense of resolution.[1,2] The I^2 tube has a fixed number of pixels (picture elements). If the pixels are spread over a larger FOV, the angular subtense per pixel increases proportionally thus reducing resolution. An extensive survey of U.S. Air Force NVG users showed that increased FOV was the most desired enhancement by aircrew members. Resolution was a close second.[3,4] This was a motivating factor for the development of an enhanced NVG capability. Previous studies suggest FOV produces performance advantages: A study using a critical tracking task showed best performance at 80 or 100 degrees. and an increase from 40 to 80 degrees greatly reduced subjects' workload.[5] Another study included a series of low altitude maneuvers in Cobra and Lynx rotorcraft and the results indicated 100 degree to unrestricted FOV required only moderate pilot compensation. The results also showed pilots flying with restricted FOV reported better flying performance than actually exhibited. Furthermore, restricted FOV inhibited detection of multiple cues concurrently. and the small FOV required more head movement and a different scan technique while large head movements led to aircraft control difficulty and disorientation.[6] A third study had subjects visually acquire targets, remember the location of the target, and monitor target threat status while performing a secondary task. Error decreased as FOV increased until a FOV of 90 degrees was reached. Secondary task performance increased as FOV inceased.[7]

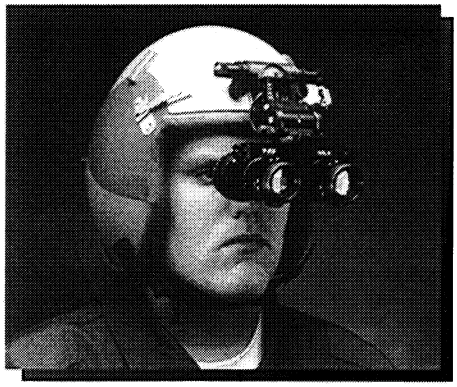

Figure 5: F-4949 NVG

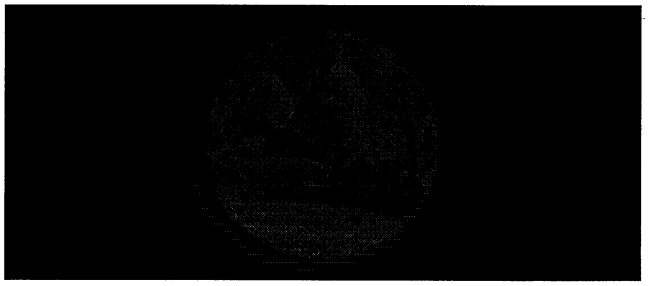

Figure 6: 40 Degree Field of View

PNVG COMMENTS

The following comments have been collected via post flight questionnaires. PNVG I comments represent feedback from F-15C and F-15E aircraft from the 422 Test and Evaluation Squadron at Nellis AFB, Nevada.[8] PNVG II comments represent C-130 feedback from the 50th and 61st Airlift Squadrons at Little Rock AFB, Arkansas and C-5 feedback from the 3rd and 9th Airlift Squadrons and 436th Air Wing at Dover AFB, Delaware.[9]

Representative PNVG I positive comments

"I did not experience any eye strain or headaches." "A must have." "A-10's need these!" "Closer to face, better FOV rather obvious!" "Outer channels were focused much better (20/25)." "Had better situational awareness of my surroundings." "Easier to fly at lower altitudes." "Could spend more time scanning for bandits and watching where my flight path is." "Less forward CG when looking through."

Representative PNVG I negative comments

"Lack of adjustability." "The battery change out is unsat." "I lost a battery down inside the helmet cover when trying to change out!" "In order to see the HMD display, I had to have the right channels way over to the left (toward the center of my face)." "This caused me to lose the outer part of the right outer channel." "Need to adjust focus rings." "They are too hard to work with gloves on." "Need more play in the areas that we normally focus (infinity)." "The "bridge" that holds the goggle is worn and breaks loose at 6 g's or greater." "Requires me to reach up and snap it back into place." "More difficult to see inside the cockpit, especially under g's." "Very difficult to set up the radar while in turn." "Not as crisp." "Flimsy trapeze, tilt sags under G." "Adjustments not user friendly." "Had to lower seat 2 inches to get proper eye height relative to HUD." "Delicate innards exposed when removed from helmet for stowing."

Representative PNVG II positive comments

"The panoramic vision greatly increased mission capabilities by decreasing the amount of head movement required for the pilot to scan. This in turn reduced the amount of work." "Overall very impressive--much less time scanning, much more time spent looking--situation awareness dramatically increased." "PNVGs definitely enhance mission effectiveness. The peripheral vision alone is a dramatic capability enhancement. The battery pack incorporated into the PNVG is also nice." "Panoramic vision greatly increases SA and clearing ability."

Representative PNVG II negative comments

"PNVGs need: wider range of focus. Outer tubes need focus ability, more field of view up and down would be nice too." "PNVG objective lens seem harder to adjust than 4949, the knobs are hard to turn. Very heavy when stowed. PNVG needs more near focusing for close up work (1 - 2 foot range)." "Suggest better focus on inner tubes and focus capability on outer tubes." "Also because you need the NVGs close to your eyes to eliminate the "lines" it makes viewing cockpit instruments difficult under the PNVGs compared to the 4949s."

I-PNVG OBJECTIVES

There are nine areas that address the key Air Force objectives of the I-PNVG program.[10] These areas are discussed in the following paragraph The first key objective is *wide FOV*. The PNVG I and PNVG II systems developed under the SBIR program did not perform trade studies to determine the optimal FOV. The I-PNVG program will review the literature and conduct trade studies to develop an optimal FOV design. The system will be required to have an instantaneous horizontal FOV $\geq$ 80 degrees with a binocular overlap $\geq$ 36 degrees, and a instantaneous vertical FOV $\geq$ 36 degrees. The second key objective is *laser eye protection*. Laser threats to military aircrew are real with reports from foreign sources and the presence of lasers are expected to grow on the battlefield. These incidents have raised concern for the health of aircrew eyes, for mission effectiveness, and for flight safety. I-PNVG will incorporate LEP technologies for protection of the human and the goggles. The design(s) will have to accommodate the latest LEP visor, LEP spectacles, and light interference filters. The third key objective area is *fit and comfort*. The fit and comfort of the operator while wearing the I-PNVG will be examined. The I-PNVG will need to accommodate a diverse population of operators that will be flying in different mission environments of varying mission duration. Design considerations will be weight and center of gravity (down and stowed positions), ease of mechanical adjustments, stability of the NVG/helmet to accommodate G loads and rapid head movements, cockpit compatibility, and adequate eye relief. The fourth key objective area is *image quality*. The device needs to have image quality equal to or better than NVGs delivered under the Army Omni V contract. Attributes for satisfying the requirement that need to be considered are the expected visual acuity (resolution) through the device for quarter moon and starlight levels, signal-to-noise ratio, image tube halo, optical distortion, optical image alignment, system modulation transfer function (MTF - on axis and at edges of the field), eyepiece focus, eye position tolerance and effects on optical MTF, objective lens focus, and maximum image luminance. If partial overlap of visual fields is used to produce the wide FOV, the

image discontinuity tolerances at the overlap should be addressed including image luminance uniformity, image magnification, rotation, distortion, and horizontal and vertical off-set. The fifth key objective area is *integrated symbology/imagery display*. The electronic interface needs to be extended from the current symbology overlay technique to include imagery insertion by using a light-valve or similar technology (could even include turning image intensifier tube off) to block the NVG image during imagery display and single-channel miniature camera record. The inclusion of a full-color version of the miniature flat panel image source will also be considered. The I-PNVG will provide the capability to remove/replace either or both the flat panel image source and the miniature camera in the field. The I-PNVG will remain mission capable as a separate functioning system with either or both functions removed. The instantaneous FOV provided for the imagery insertion should be compatible with current navigation-FLIR sensors. Compatibility with Joint Helmet Mounted Cueing System, Visually-Coupled Acquisition & Targeting System, Air Warrior, and Land Warrior will be considered. Finally, the allocation of electronics between the I-PNVG device and its associated helmet vehicle interface module will be addressed with respect to its impact on operational use of the system. The sixth key objective area is *field support*. The device should be designed in order to minimize the need for any additional logistic support equipment. This means the design will allow field-level performance testing utilizing the ANV-126 Hoffman tester with little or no disassembly of the I-PNVG device or major modification to the tester. Adjustment knobs should be useable while wearing flight and chemical/biological gloves. The seventh key objective area is *ejection/crash/ground egress safety.*[11] Flight safety and environmental use have to be factored into the design. The following areas need to be examined in the performance of safety testing: Mertz criteria, Knox Box, USAARL curve, inertial properties, vertical impact, helmet impact, visor ballistics, helmet penetration, rapid and explosive decompression, ejection windblast, quick disconnect functionality, hanging harness, cockpit compatibility, electromagnetic compatibility, emergency ground egress, and electrical shock analysis. The eighth key objective area is *compatibility with existing systems*. The new system will need to be interoperable with existing systems. The items that need to be addressed are the helmet, oxygen mask, nuclear/biological/chemical masks, Aviator Night Vision Imaging System mount, survival vest, anti exposure suit, torso harness, aircrew spectacles, back style parachutes, and personal clothing. The ninth and final key objective area is – *ilities*. The I-PNVG design must optimize reliability, maintainability, affordability, producibility and supportability. System and system sub-components should be capable of mass production while consistently maintaining pre-established standards. A design that requires only minimal maintenance is desirable. Pre or post-flight checkout and maintenance procedures should be kept to a minimum. Major components should be interchangeable if a two-configuration approach is adopted.

I-PNVG PRELIMINARY DESIGN CONSIDERATIONS

A single I-PNVG design approach is preferred that would satisfy mission requirements for fighters, bombers, transports, helicopters, and ground personnel. If a two-design approach is deemed necessary commonality of components between the designs is to be emphasized. A trade-off of the above listed objectives is critical in order to optimize the desired approach(s). Some of the specific parameters of interest for the I-PNVG trade-off studies are total horizontal field-of-view, binocular overlap, resolution/visual acuity, eye relief/lens focal length, weight, center of gravity, F/Number (lens diameter), exit pupil, image quality/MTF, size/form factor, adjustments, manufacturability/maintainability, and cost. The following parameters are identified as "non-negotiable": must have same visual acuity as F-4949, must be compatible with standard flight spectacles, and must use 16mm tubes. Other important issues that need to be addressed are the tolerances at the inboard/outboard seam (rotation, vertical mismatch, horizontal mismatch, magnification mismatch, distortion), inboard/outboard mismatch for other than infinity objective lens settings, and alignment procedures for inboard/outboard channels. Initially, two approaches are being considered. The first is a low profile "periscope-like" design (referred to as I-PNVG 1) targeted for ejection seat aircraft (Figure 7). This design approach intends to permit the system to be retained on the head safely during the ejection sequence and additionally provide post-ejection evasion and rescue capability while on the ground. Each of the identical objective lenses are adjustable for distance focusing and feature a fixed, fused, and tilted eyepiece design. I-PNVG 1 utilizes folded optics in each of the four optical channels, fits underneath a standard Air Force visor, and attaches to the standard Air Force HGU-55/P helmet via a universal connector. This universal connector is hard mounted to the helmet and is the same mounting mechanism approach used for two daytime helmet mounted display systems currently being tested (1) AFRL's Visually-Coupled Acquisition and Targeting System [VCATS] (an advanced technology demonstration effort) and (2) Common Avionics System Program Office's Joint Helmet Mounted Cueing System [JHMCS]) (an engineering and manufacturing development program). A dummy universal connector will also be fabricated onto a banana clip-like mount for non-JHMCS and non-VCATS aircraft. An enhanced version of I-PNVG 1, referred to as Strike Helmet 21, will use the I-PNVG 1 as its baseline but will integrate some new technologies under development. These new technologies include an Active-Matrix Organic Light Emitting Diode for symbology or video display and an inertial head tracking system to help precisely deliver high off-boresight angle missiles. A CCD camera will also be integrated and used for battle damage assessment and training purposes. The second approach being considered (referred to as I-PNVG 2) is a more "traditional" design (Figure 8) for transports, helicopters, and ground personnel. This approach utilizes straight-through optics, similar to

AN/AVS-6 and F-4949, in each of the four optical channels and attaches to the standard Air Force HGU-55/P or SPH-4/AF helmet via an "ANVIS-like" mount. Each of the identical objective lenses (like I-PNVG 1) are adjustable for distance focusing and feature a fixed, fused, and tilted eyepiece design. A trade study has been initiated on whether it is possible and advantageous to adapt aspects of this second approach (i.e. straight-through optics) for the ejection seat aircraft design (i.e. I-PNVG 1) as well. There are some likely advantages of a straight-through optics approach that would benefit I-PNVG 1 such as improved optical performance, easier alignment in manufacturing, and commonality with the monocular used for the "traditional" straight-through optics on I-PNVG 2. Questions exist though on the weight and center of gravity of this straight-through optics approach and whether it would fit underneath a standard Air Force visor. This is where we will look to the trade study results. This straight-through optics approach, in addition to being common to both the I-PNVG 1 and the I-PNVG 2, would also be common to the Army's design which is being developed jointly under the I-PNVG program. The Army tracks their advanced technology demonstration design as the "Advanced Night Vision Goggle" (ANVG) (Figure 9) and manage it at the Night Vision and Electronic Sensors Directorate, Ft. Belvoir. The commonality of approaches between the services could provide tremendous synergism. Weight and Space Models of the I-PNVG 1 are scheduled for delivery in May 2001 and the first operational deliveries of the I-PNVG 2 are to begin in August 2001. I-PNVG 1 and ANVG deliveries will follow shortly thereafter.

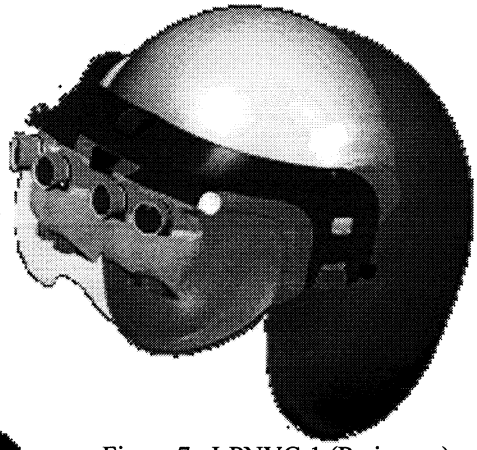

Figure 7: I-PNVG 1 (Periscope)

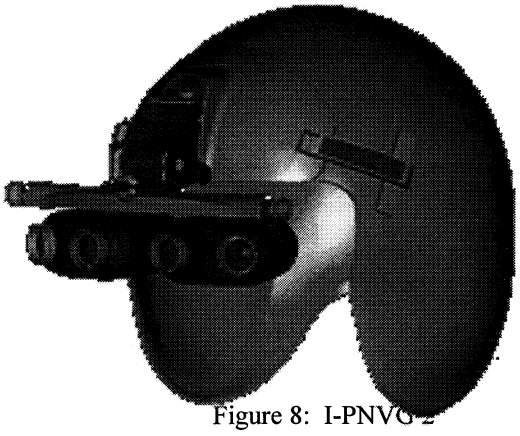

Figure 8: I-PNVG 2

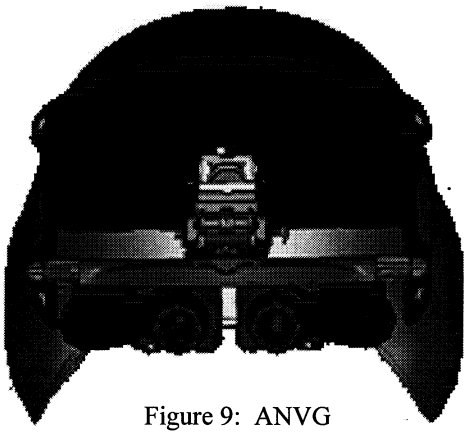

Figure 9: ANVG

CONCLUSION

The I-PNVG truly has the potential to become the next generation night vision goggle. Work continues towards finalizing the optical, mechanical, and electronics design details prior to the scheduled critical design review in January 2001. Stereo lithography models will be utilized extensively over the next several months by the designers and warfighters to explore and/or verify I-PNVG design options. Weight and space models will be available in May 2001 to enable safety of flight testing to begin followed by the first operational I-PNVG deliveries in August 2001. The Air Force is scheduled to receive a total of 25 I-PNVGs and the Army is scheduled to receive a total of 5 ANVGs for flight evaluation purposes.

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BIOGRAPHY

Mr. Jeff Craig is an Industrial and Systems Engineer working for the Air Force Research Laboratory. A graduate of Ohio State University in 1982, Mr. Craig has been employed at Wright-Patterson Air Force Base in Ohio since receiving his diploma. His current position is managing the Night Vision Operations Program within the Air Force Research Laboratory. Early projects to his credit are NVG compatible cockpit lighting, NVG head-up displays, and NVG covert landing aides. More recent efforts have centered around new NVG developments in particular the PNVG and I-PNVG programs.